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Dryland Grain Sorghum Water Use, Light Interception, and Growth Responses to Planting Geometry

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Dryland Grain Sorghum Water Use, Light Interception, and Growth Responses to Planting Geometry[1]

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ABSTRACT

Crop yields are primarily water-limited under dryland production systems in semiarid regions. This study was conducted to determine whether the growing season water balance could be manipulated through planting geometry. The effects of row spacing, row direction, and plant population on the water use, light interception, and growth of grain sorghum [*Sorghum bicolor* (L.) Moench] were investigated at Bushland, TX, on a Pullman clay loam (fine, mixed, thermic Torrertic Paleustoll). In 1983, which had a dry growing season, narrow row spacing and higher population increased seasonal evapotranspiration (ET) by 7 and 9%, respectively, and shifted the partitioning of ET to the vegetative period. Medium population crops yielded 6.2 and 2.3 Mg/ha of dry matter and grain, respectively. High population resulted in high dry matter (6.1 Mg/ha) and low grain yield (1.6 Mg/ha), whereas low population resulted in low dry matter (5.4 Mg/ha) and high grain yield (2.3 Mg/ha). Row direction did not affect water use or yield. In 1984, dry matter production for a given amount of ET and light interception was higher in the narrow-row crops. Evapotranspiration was less for a given amount of light interception in the narrow-row crops and in the north-south row crops. Narrow-row planting geometry appears to increase the partitioning of ET to the transpiration component and may improve the efficiency of dryland cropping systems.

Additional index words: **Evapotranspiration, Evaporation from soils, Transpiration, Row spacing, Row direction, Row orientation, Population, *Sorghum bicolor* (L.) Moench.**

CROP yields in the southern Great Plains are primarily water-limited under dryland production systems. To increase the supply of soil water for crop production, the efficiency of precipitation storage during noncropping periods must be increased or partitioning of evapotranspiration (ET) from the soil surface to plant transpiration must be manipulated. Residue management has been effective in increasing the amount of water available for crop growth by about 35 to 75 mm (Unger, 1978, 1984) through increased storage of precipitation in the soil profile during fallow periods. Stewart (1986) indicated that each additional millimeter of water available for ET increases grain sorghum [*Sorghum bicolor* (L.) Moench] yield 15.5 kg/ha at Bushland, TX. Further improvements in the productivity of dryland systems might be possible through manipulation of agronomic practices, such as row spacing, plant population, and row orientation, which affect the partitioning of radiant energy between plant and soil surfaces.

Research conducted in the late 1960s and early 1970s indicated that narrow-row sorghum crops produce higher dry matter and grain yields for a given level of ET under irrigation or in humid and subhumid conditions (Grimes and Musick, 1960; Kanemasu and Arkin, 1974; Porter et al., 1960; Stickler et al., 1961; Witt et al., 1972). In contrast, experiments conducted at Bushland (Bond et al., 1964) and elsewhere (Bielorai et al., 1964; Brown and Shrader, 1959) suggested that the risk of grain yield reduction was greater with narrow compared with wide rows under semiarid conditions. Bond et al. (1964) measured greater depletion of soil water before anthesis in the narrow-row plots but found population effects to be greater than row spacing effects. When their plots had high soil water at planting, greater dry matter and grain yields were produced by the narrow-row crops. As conservation tillage systems are adopted throughout the Great Plains, resulting in increased soil water at planting, the use of narrow row planting systems may offer a possibility of manipulating growing season ET without excessive risk of reduced yield.

Dryland crop production accounts for about 58% of the harvested area and 34% of the yield of grain sorghum in the Texas High Plains (USDA, 1984). To improve dryland production practices for this region, a quantitative understanding of crop water use through the growing season as affected by management practices is needed. This paper describes the effects of row spacing, row orientation, and plant population on the water use, light interception, and growth of grain sorghum.

MATERIALS AND METHODS

The experiment was conducted at the USDA-ARS Conservation and Production Research Laboratory at Bushland, TX, in 1983 and 1984. Grain sorghum (hybrid 'DK46')[3] was planted on 8 June 1983 and 7 June 1984. The sorghum followed a winter wheat (*Triticum aestivum* L.) crop in rotation, with the wheat residue being managed through an 11-month fallow period by stubble mulch tillage in 1983 and by no-till management in 1984. No fertilizer was added to the plot area. Eck and Fanning (1962) showed no fertilizer response for dryland crop production on the Pullman clay loam (a fine, mixed, thermic Torrertic Paleustoll) because of inherently high fertility and low expected yields.

The experimental treatments were row spacing (0.38- and 0.76-m rows), row orientation [north-south and east-west (NS and EW)], and seeding rate [6, 12, and 18 plants/m^2 (L, M, and H populations, respectively)]. The actual plant establishment was 6.9, 13.1, and 18.6 plants/m^2 in 1983 and 5.4, 7.8, and 11.5 plants/m^2 in 1984. Poorer plant establishment in 1984 was probably related to dry surface soil at the time of planting, which resulted in poor penetration of the seeding unit into the soil. The treatments were imposed as two factorial experiments, which are summarized in Table 1. Plots were 9 by 9 m in 1983 and 9 by 15 m in 1984, planted in randomized, complete blocks with three replications. Blocking was used to isolate the possible diurnal effects in light interception and plant water status measurements, but no significant blocking effect was seen in the data.

Soil water was measured weekly from 2 weeks after sowing until harvest, using a single neutron probe access tube in each plot. Readings were taken at 0.2-m intervals from 0.2 to 1.6 m and converted to volumetric soil water content with a single calibration equation, which was determined in 1983 at the experimental site. The surface 0.15 m was sampled

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[3] Mention of a trade name or product does not constitute a recommendation or endorsement for use by the USDA.

Table 1. Summary of treatments† in the row spacing and population experiment (I) and the row spacing and direction experiment (II).

Experiment		Treatments		
I	II	Row direction	Row spacing	Population
			m	
X		EW	0.38	H
X	X	EW	0.38	M
X		EW	0.38	L
X		EW	0.76	H
X	X	EW	0.76	M
X		EW	0.76	L
	X	NS	0.38	M
	X	NS	0.76	M

† The eight treatments were randomized within each block. Medium population, EW row plots were included as treatments in both experiments.

gravimetrically. Evapotranspiration for each period was calculated as the change in soil water over the period plus rainfall. Runoff was assumed to be insignificant because of the low slope (< 7 m/km), high residue level, and soil cracking. The upper and lower limits of available soil water were measured in the field near the plot area in 1983 using the techniques of Ritchie (1981). The volumetric soil water is about 0.30 m^3/m^3 at the upper limit and 0.18 m^3/m^3 at the lower limit, with 0.195 m of available water in a 1.7-m profile.

Plants were sampled weekly from emergence to harvest for measurement of leaf area index (LAI) and dry matter. Four contiguous plants were collected from each plot for processing and converted to a unit-area basis using plant establishment counts. For each treatment, fifth and fourth order polynomial equations were fitted to describe LAI and dry matter accumulation curves, respectively, as a function of days after sowing to smooth the data and to obtain average LAI and dry matter accumulation over the periods defined by ET measurements. Figures 3–6 present average LAI and dry matter as generated by the equations for the period of interest. Final yield samples were taken by cutting plants at the soil surface in two areas (2.28 to 3.04 m^2, depending on row spacing and year) of each plot. Yields reported are oven dry weights.

Interception of photosynthetically active radiation (PAR, 400 to 700 nm waveband) was measured using quantum sensors. Incoming PAR and reflected PAR, at about 1 m above the canopy, were measured with LiCor[3] 190SB sensors (LI-COR, Lincoln, NE) with 1 cm^2 of sensor surface area. Transmitted PAR at the soil surface and reflected PAR 0.1 m above the soil were measured with light bars (LiCOR[3] 191SB Line Quantum Sensors) with sensor surface dimensions of 0.12 by 1.0 m. The sensors at the surface were mounted in brackets, which were located at the same place throughout the sampling period. The brackets were located so that the sensors angled across a single interrow space in the 0.76-m plots and across two interrow spaces in the 0.38-m plots, spanning from row to row. Reflectance above the canopy was measured with the quantum sensor centered over a row. Measurements were made from early August through mid-September 1983 on six clear to partly cloudy days at about 1300 h CDT. A series of 10, 1-ms scans per plot was recorded and averaged using an Omnidata Polycorder (Omnidata International, Logan, UT).[3] In 1984, data were collected from mid-July through mid-September on a single replication of the experiment (eight plots). The data were scanned at 6-s intervals and averaged over 30-min periods 24 h a day using a Campbell Scientific, Inc. CR-7[3] data acquisition system (Campbell's Scientific, Logan, UT).

Intercepted solar radiation was estimated from PAR assuming 2.05 mole photons/MJ (Howell and Meeks, 1983). The soil and canopy reflectance properties are not the same in the visible and solar spectral ranges, but errors involved in making the conversion should be systematic and should not interfere with analyzing the interactions of light interception and evapotranspiration as affected by the treatments.

The climatic conditions during the two growing seasons are summarized in Fig. 1. In 1983, a wet, cool spring resulted in a moist soil water profile at planting, but conditions were hot and very dry during the growing season. Rainfall was only 68 mm for the growing season, including 11 mm in August and September, leading to severe stress during the heading and grain-filling periods. In 1984, a dry spring resulted in a low soil water content at planting, but fairly regular rains fell from 3 days after planting through most of the season, with 108 mm in August and September and a seasonal total of 273 mm. Temperatures during the heading and grain-filling periods were an average of 2.6°C cooler in 1984 than in 1983. Climatic data were collected at a weather station about 3 km from the plot area in 1983 and at the plot site in 1984. Rainfall data were collected near the plot areas in both years.

RESULTS AND DISCUSSION

The effects of the row spacing, populations, and row direction on water use and yield of sorghum are shown in Tables 2 and 3. The treatment effects were more pronounced in the droughty conditions of 1983 than in the relatively moderate 1984 season. Narrow rows and the H and M population had higher seasonal ET due to higher ET during the period from emergence through anthesis. High population treatments reduced sorghum yields in both row spacing treatments.

In 1984, narrow rows increased sorghum dry matter production significantly but had no significant effect on grain yield. The wide-row plots had reduced ET in the vegetative period leading to a greater percentage of water used in the grain-filling period and an increased harvest index. There was no dry matter or yield response to population in 1984, possibly because of the smaller range of population levels than in 1983 and the more favorable growing season. Because of sorghum's tillering response, low plant population is not likely to be limiting to dryland production in favorable years. High plant population can be very detrimental in dry years due to excessive depletion of the soil water early in the season as seen in 1983. Row orientation of sorghum did not significantly affect water use or yield in either year.

Seasonal ET and total dry matter production were weakly correlated in 1983 and not significantly correlated in 1984 (Table 4). This is contrary to results that would be expected in a more humid environment and is explained by the dominant effect of the vegetative period ET on seasonal ET and the negative correlation between ET during the vegetative and grain-filling periods. With crop production strongly dependent on stored soil water, the timing of ET affects the dry matter production. Evapotranspiration during the early stages of crop growth has a strong component of evaporation from the soil surface (E). Evapotranspiration during the vegetative period was negatively correlated to harvest index in both years of the experiment. When the 2 years' data were pooled, the correlation between ET and grain and dry matter production was evident.

Interception of PAR by the canopy in 1984 was affected primarily by row spacing, as shown in Fig. 2.

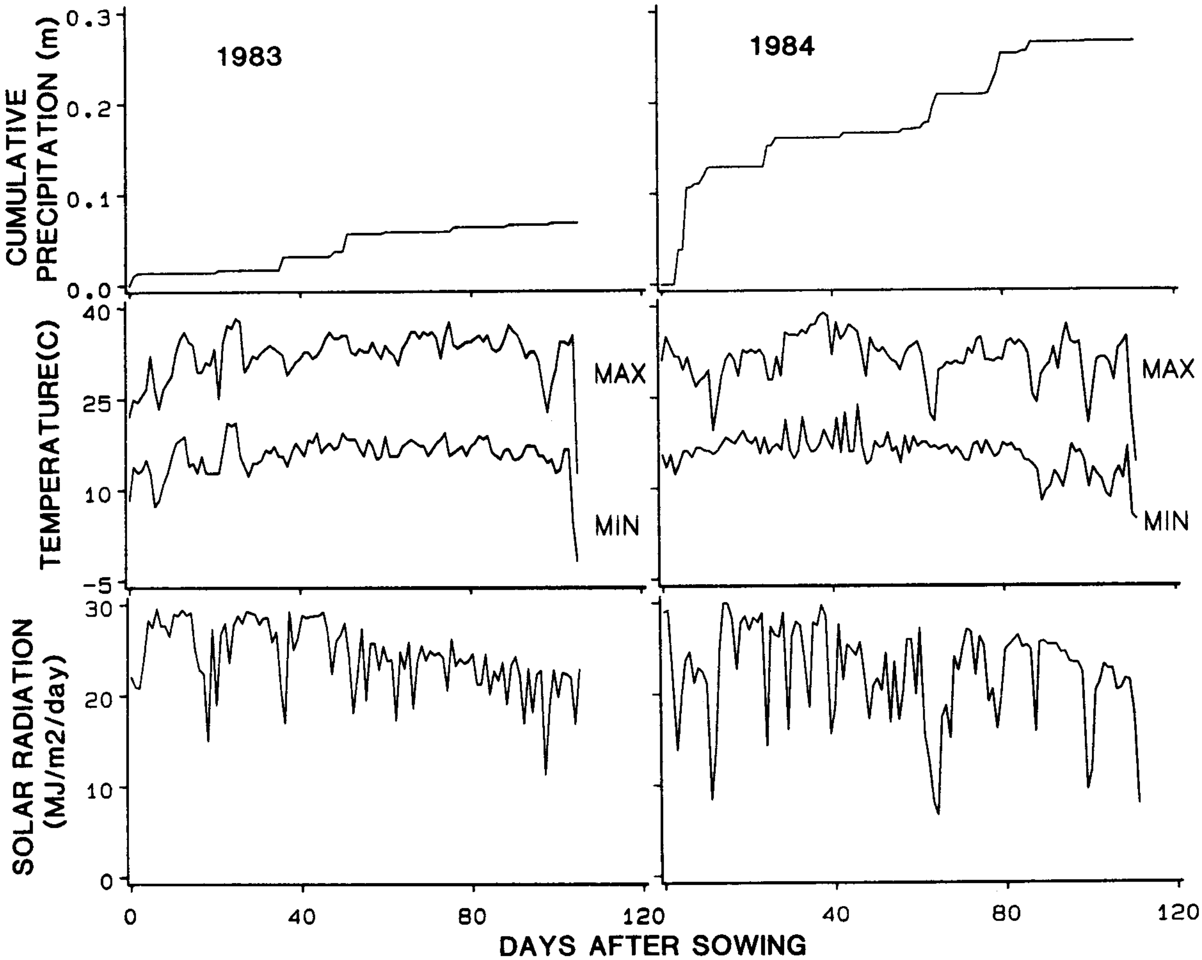

Fig. 1. Summary of growing season climatic conditions: (*a*) cumulative rainfall, (*b*) maximum and minimum temperature, and (*c*) solar radiation, Bushland, TX, 1983 and 1984.

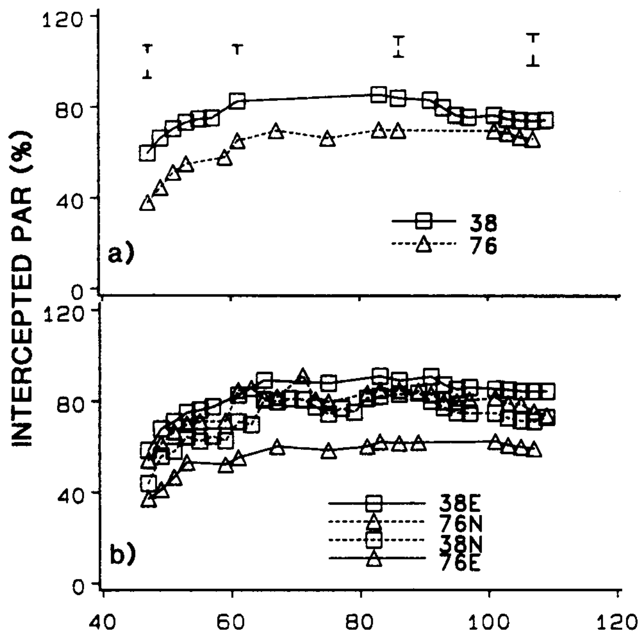

Fig. 2. Intercepted photosynthetically active radiation (IPAR) in dryland sorghum as affected by (*a*) row spacing and (*b*) row direction, 1984. Bars show the standard error of the mean IPAR for selected dates.

Since population effects were small, the interception data for all three population levels were averaged to give three plots to examine each row spacing (Fig. 2a). The maximum light interception by the canopy in the narrow rows was about 80% of the daily incoming PAR, compared with about 70% in the wider-spaced rows. Differences between the row spacing treatments were greater early in the season. The effects of row direction interacted with row spacing, with the narrow, EW-row crops intercepting the highest amounts of radiation and the wide, EW-row crops intercepting the least. Wide and narrow NS-row crops intercepted intermediate amounts of radiation (Fig. 2b). The ANOVA of the replicated 1983 light interception data showed similar results to those found in 1984, with row spacing significantly affecting mid-day light interception ($P < 0.05$) but no significant effect of population or row direction on light interception.

Data collected in 1984 allowed for analysis of interactions of ET, dry matter production, LAI, and light interception through the season. Soil moisture depletion was measured at weekly intervals and ET, dry matter accumulation (DDM), average LAI, and light interception (INT) were calculated for each period between soil water measurements. Figures 3 and 4 show the relationship of LAI to cumulative ET and cumulative light interception from 47 to 110 days after sowing. In spite of up to 20% higher LAI, the narrow-

Table 2. Row spacing and population effects on ET, yield, and water use efficiency (WUE) of dryland grain sorghum.

Treatment	Seasonal ET	Vegetative ET	Grain-fill ET	Percent of ET during grain-fill	Total dry matter	Grain dry matter	Harvest index	WUE total	WUE grain
	m			%	Mg/ha			kg/m³	
				1983					
Spacing†									
38	0.200**	0.175**	0.025*	12**	5.92	2.03	0.34	2.96*	1.02*
76	0.184	0.151	0.033	18	5.92	2.13	0.36	3.22	1.16
Population									
H	0.199**	0.174**	0.025	13*	6.10*	1.64**	0.27**	3.08	0.83**
M	0.194	0.166	0.028	14	6.22	2.31	0.37	3.21	1.18
L	0.183	0.149	0.033	18	5.44	2.28	0.41	2.98	1.25
SE	0.011	0.009	0.010	4.9	0.72	0.44	0.04	0.35	0.20
CV (%)	5.5	5.6	35.9	33.1	12.2	21.4	11.0	11.0	18.6
				1984					
Spacing									
38	0.266	0.187**	0.078	29*	9.52*	3.33	0.35**	3.58**	1.25
76	0.265	0.175	0.089	34	8.13	3.29	0.40	3.08	1.25
Population									
H	0.263	0.184	0.078	30	9.41	3.39	0.36	3.56	1.28
M	0.269	0.183	0.085	31	8.45	3.20	0.38	3.16	1.19
L	0.264	0.177	0.087	33	8.61	3.34	0.39	3.26	1.27
SE	0.013	0.008	0.012	35	1.05	0.50	0.02	0.33	0.18
CV (%)	5.0	4.5	14.8	11.2	11.9	15.0	6.3	10.0	14.5

**,* Significant at 0.01 and 0.05, respectively.

† Significant ($P < 0.05$) spacing × population interactions in 1983 in harvest index and grain water use efficiency. No significant spacing × population interactions in 1984.

row plots did not exhibit higher ET than the wide-row plots. They did, however, intercept more radiation (Fig. 4a), indicating a higher proportion of the ET being through plant transpiration. The M population plots had slightly higher LAI than the H and L plots, but ET (Fig. 3b) and light interception (Fig. 4b) were similar at all population levels. Row direction did not have a large effect, but ET was slightly higher (Fig. 3c) and light interception was slightly lower (Fig. 4c) in the EW-row crops for similar LAI.

More dry matter was produced for a given level of cumulative ET in narrow-row compared with wide-row crops (Fig. 5a) and in NS-row compared with EW-row crops (Fig. 5c). Late in the season, narrow-row and NS-row crops produced greater dry matter for a given level of light interception by the canopy (Fig. 6).

The wide-spaced rows resulted in higher ET for given levels of light interception than the narrow-spaced rows, because plants in wide rows took longer to accumulate a given level of IPAR by the canopy (Fig. 7a). This may indicate a higher proportion of evaporation from the soil surface for a given level of cumulative ET. A similar response is seen when comparing EW rows with NS rows (Fig. 7c). All population levels showed the same relationship between cumulative light interception and ET (FIg. 7b).

Table 5 shows the correlation among ET, dry matter production, LAI, and light interception from eight treatments over 13 periods of the 1984 growing season. The ET within any given period was significantly correlated to light interception within the period (r = 0.57), dry matter accumulated within the period (r = 0.32), and LAI (r = 0.31). Correlations were very high among cumulative variables. The cumulative ET was significantly correlated to dry matter produced from emergence to the end of the period (r = 0.96), to accumulated light interception (r = 0.96), and at a lower level to LAI, light interception within a period, and dry matter accumulation within the period.

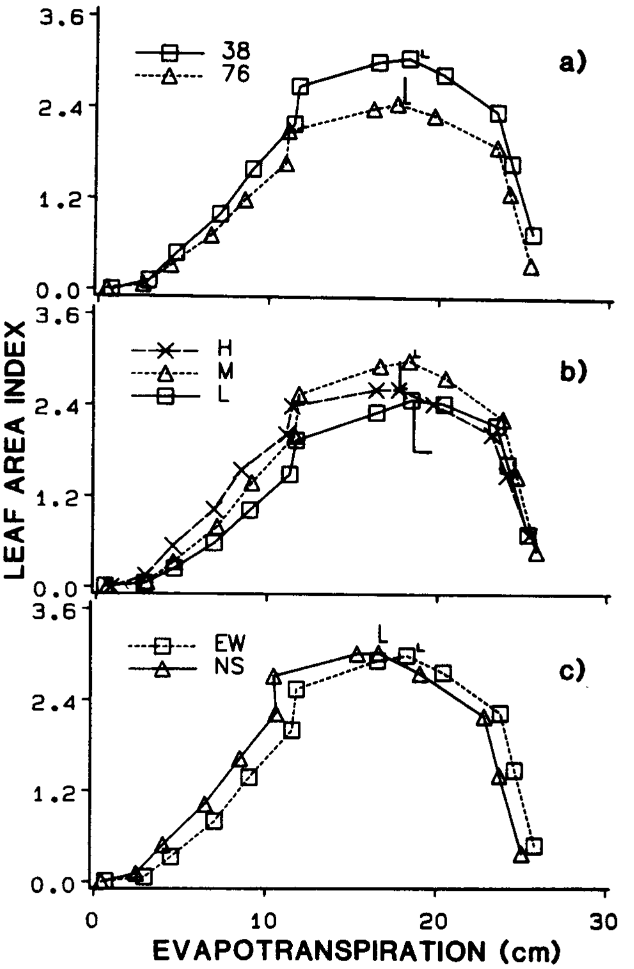

Fig. 3. Cumulative ET and LAI of dryland grain sorghum as affected by (*a*) row spacing, (*b*) population, and (*c*) row direction, 1984. Horizontal and vertical bars show the standard error of the mean of the *x* and *y* variables, respectively, for extreme points.

Table 3. Row direction effects on ET, yield, and water use efficiency (WUE) of dryland grain sorghum.

Treatment	Seasonal ET	Vegetative ET	Grain-fill ET	Percent of ET during grain-fill	Total dry matter	Grain dry matter	Harvest idnex	WUE total	WUE grain
	m			%	Mg/Ha			kg/m³	
				1983					
NS†	0.187	0.160	0.027	15	6.13	2.31	0.38	3.28	1.24
EW	0.194	0.166	0.028	14	6.22	2.31	0.37	3.21	1.19
SE	0.009	0.010	0.008	4.2	0.86	0.55	0.05	0.41	0.25
CV	5.1	6.5	30.8	29.0	14.0	23.9	13.3	12.6	21.0
				1984					
NS	0.260	0.166	0.093	36	8.49	3.45	0.40	3.28	1.34
EW	0.269	0.183	0.085	31	8.45	3.20	0.38	3.17	1.19
SE	0.012	0.014	0.012	4.4	0.90	0.60	0.04	0.42	0.26
CV	4.5	7.8	13.8	13.0	10.7	17.4	9.4	13.1	20.7

† No significant effects ($P < 0.05$) due to row direction or direction × spacing interactions in either year.

Narrow rows improve the performance of many crops in humid regions or under irrigated conditions through maximizing the capture of incoming solar radiation (Kanemasu and Arkin, 1974; Witt et al., 1972). In semiarid, dryland production, the management of soil water depletion is more critical than the capture of radiation, which is far more abundant than water. Narrow row spacing increased dry matter production and production of dry matter per unit ET (Table 2 and Fig. 5a) in 1984, and increased light interception per unit ET (Fig. 7a), indicating increased partitioning of ET into the transpiration component. Although the effects are small and the increased dry matter did not result in increased grain yield, the results of this ex-

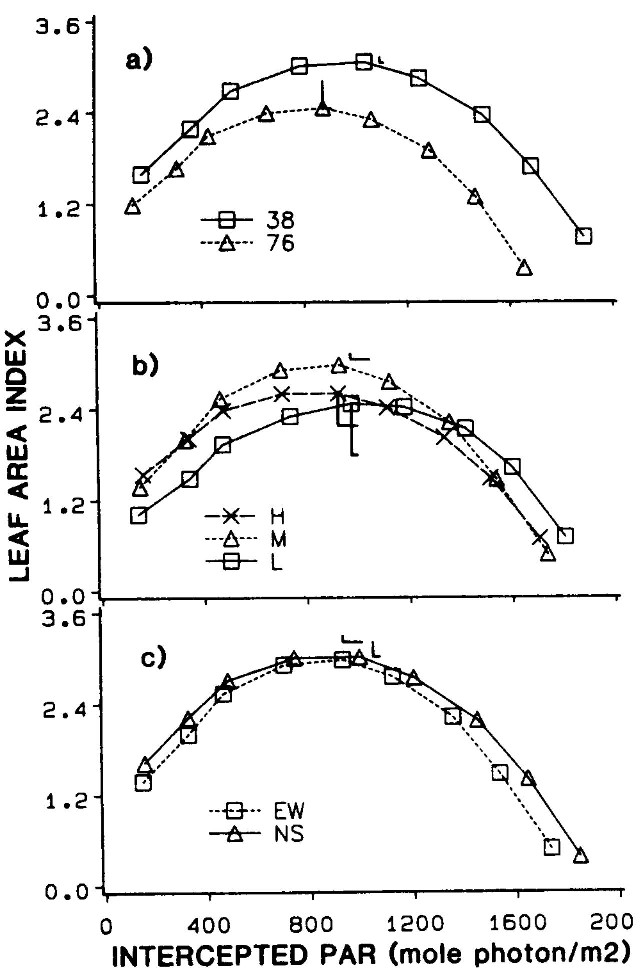

Fig. 4. Cumulative intercepted PAR (from 47 to 110 days after sowing) and LAI of dryland grain sorghum as affected by (*a*) row spacing, (*b*) population, and (*c*) row direction, 1984. Horizontal and vertical bars show the standard error of the mean of the *x* and *y* variables, respectively, for extreme points.

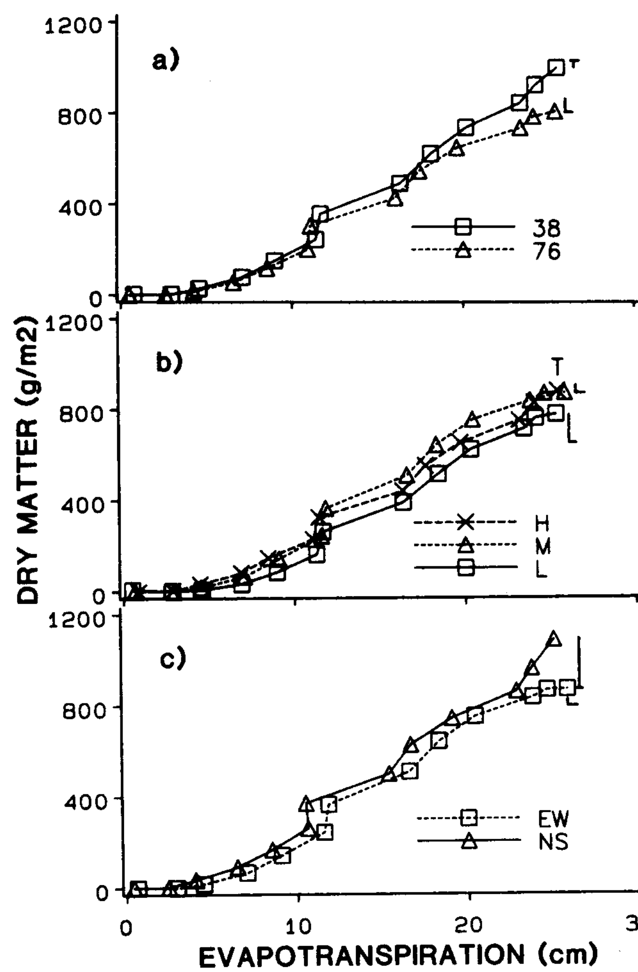

Fig. 5. Cumulative ET and dry matter production of dryland grain sorghum as affected by (*a*) row spacing, (*b*) population, and (*c*) row direction, 1984. Horizontal and vertical bars show the standard error of mean of the *x* and *y* variables, respectively, for the extreme points.

Table 4. Correlation coefficients of water use and yield of dryland sorghum, Bushland, TX, 1983 and 1984.

		Grain-fill ET	Total ET	TDM	GDM	Harvest index	WUE total	WUE grain
Vegetative ET	1983	−0.59**	0.77**			−0.46**		−0.45**
	1984	−0.59**	0.55**			−0.65**		−0.49*
	Both		0.61**	0.41**		−0.35**		−0.30*
Grain fill ET	1983				0.40**	0.42**		0.39**
	1984					0.48*		
	Both		0.89**	0.75**	0.77**	0.35**		0.35**
Total ET	1983			0.31*				
	1984							
	Both			0.80**	0.68**			
TDM	1983				0.64**		0.88**	0.54**
	1984				0.72**		0.95**	0.64**
	Both				0.85**		0.68**	0.51**
GDM	1983					0.83**	0.65**	0.97**
	1984					0.50*	0.76**	0.97**
	Both					0.65**	0.60**	0.82**
Harvest index	1983							0.86**
	1984							0.55**
	Both							0.81**

*,** Significant at the 5 and 1% levels, respectively. Correlation is of plot values.

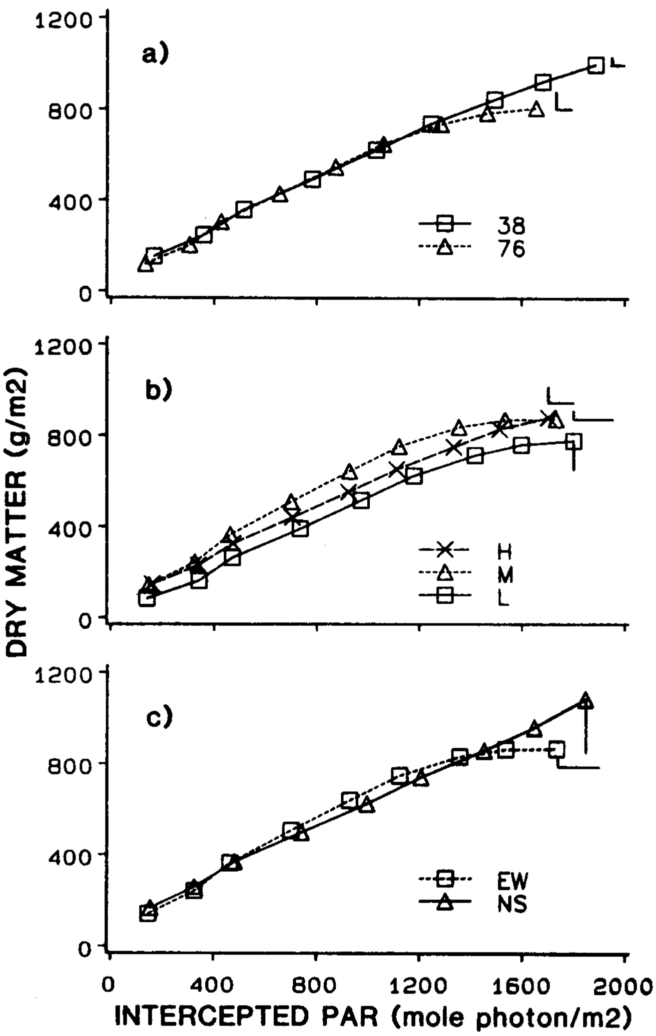

Fig. 6. Cumulative intercepted PAR and dry matter production of dryland grain sorghum as affected by (*a*) row spacing, (*b*) population, and (*c*) row direction, 1984. Horizontal and vertical bars show the standard error of the mean of the *x* and *y* variables, respectively, for the extreme points.

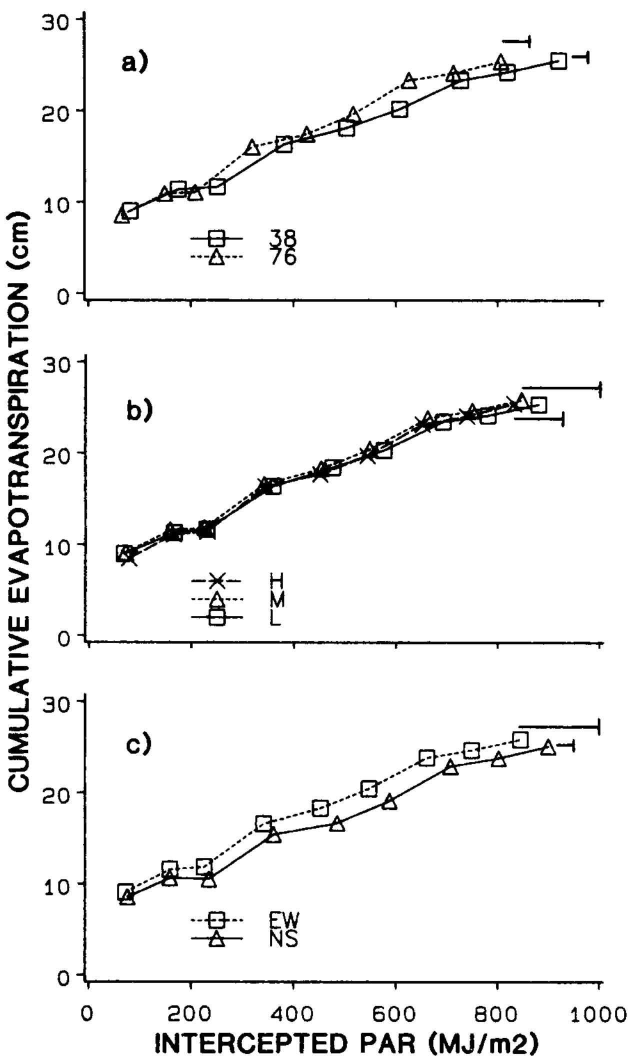

Fig. 7. Cumulative intercepted radiation and cumulative ET as affected by (*a*) row spacing, (*b*) population, and (*c*) row direction, 1984. Horizontal and vertical bars show the standard error of the mean of the *x* and *y* variables, respectively, for selected points.

Table 5. Correlation coefficients of evapotranspiration (ET), cumulative ET (ET_{cum}), dry matter production (DDM), cumulative dry matter (DM_{cum}), leaf area index (LAI), intercepted radiation (INT), and cumulative interception (INT_{cum}) for periods within the growing season of dryland sorghum, Bushland, TX, 1984.

	ET_{cum}	DDM	DM_{cum}	LAI	INT	INT_{cum}
ET		0.32**		0.31**	0.57**	
ET_{cum}		0.37**	0.96**	0.53**	0.41**	0.96**
DDM			0.38**	0.84**		−0.38**
DM_{cum}					0.34**	0.91**
LAI					0.29*	−0.27*
INT						0.43**

*,** Significant at the 5 and 1% levels, respectively. Correlation is of treatment means.

periment indicate that agronomic manipulation of dryland production systems can affect the efficiency of crop water use under semiarid conditions. Further experimentation with factors such as sorghum genotypes and planting dates may produce systems that maintain partitioning of dry matter into grain under the higher levels of production.

There is increasing adoption of tillage systems that maintain residue at the soil surface, resulting in increased soil water storage during fallow periods (Unger, 1978, 1984) and increased efficiency of rainfall utilization during the growing season (Unger et al., 1986). Conservation production systems may increase the probability of adequate soil water to use narrow-row crops, which we have shown to have a greater potential for dry matter production during the wet years, without incurring excessive risk of low yields during the unfavorable years, which Bond et al. (1964) reported. If population levels are controlled, so that excessive depletion of the soil water reservoir does not occur early in the season, then increased production may be achieved through the partitioning of ET into the transpiration component by use of narrow-row planting geometry.

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